Novel Opto-Nanomechanical Photodetector for Improving the Sensitivity of LIDAR and Local Optical Sensors

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Until recently, the most widely used technique for remote sensing was differential absorption LIDAR (DIAL). The basic principle of DIAL is based on using two radiation frequencies: one is tuned to an absorption spectral line of the species of interest, and the other is tuned off this spectral line. The attenuation of the backscattered light at these two frequencies is compared and the absorbance of the species is extracted from the difference. The main limitation of this technique is the difficulty of detecting small changes due to absorption on a large fluctuating background. To avoid this limitation, the frequency modulation (FM) technique has been applied by several research groups, including the Pacific Northwest National Laboratory (http://infrared.pnl.gov/LIDAR.htm), the NASA/Goddard Space Flight Center (www.grss-ieee.org/), and the Sarnoff Research Institute (www.sri.com/rd/Remote_Gas_Leak_Sensor.pdf).

Frequency Modulation spectroscopy has proven to be one of the most sensitive absorption-based spectroscopic techniques. The essential idea is that when a frequency modulated laser beam enters an absorbing medium the emerging, partially absorbed beam is amplitude modulated (AM). If the modulation index of the FM is sufficiently small, the spectrum of the incident FM beam consists primarily of the peak at the carrier frequency ω_c and sidebands at $\omega_c \pm \Omega$, where Ω is the modulation frequency. In addition to the component at the carrier frequency, the intensity of the output beam has a component that oscillates sinusoidally at Ω and with an amplitude proportional to the modulation index and to the difference in the attenuation coefficients of the absorber at the frequencies $\omega_c + \Omega$ and $\omega_c - \Omega$. It is important for the FM method that there be little spectral overlap between the carrier and the sidebands. If the modulation frequency is not high enough, the spectral wings of the sidebands and the carrier will

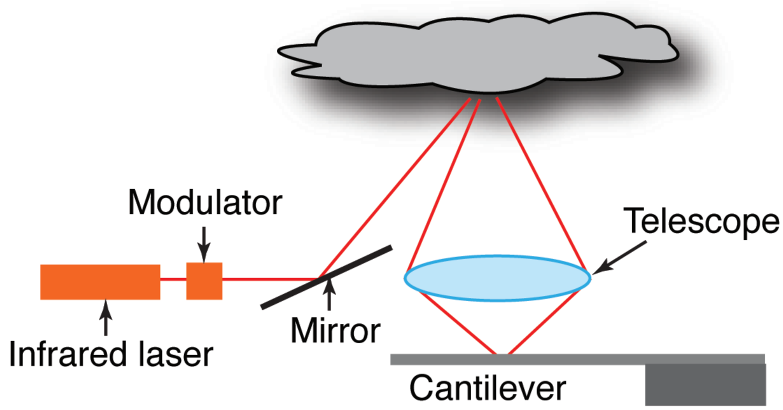

Fig. 1. *The schematic setup of the FM-LIDAR system with opto-nano-mechanical photo-detector.*

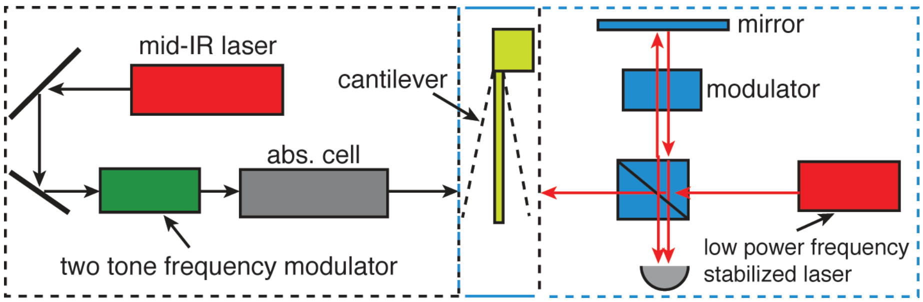

Fig. 2.
Left: FM absorption spectroscopy setup. Right: A setup for optical detection of the cantilever vibrations.

overlap, making the exact amplitude and phase balance required for full FM beat cancellation impossible. Thus, one of the major limiting factors in FM spectroscopy is laser noise, which requires that the modulation frequency be large compared with the laser bandwidth. However, electronic detection systems, consisting of a photodetector and several amplification cascades, produce an additional noise that increases with increasing modulation frequency, so that the shift to higher modulation frequency could be inefficient.

We suggest the use of nanomechanical cantilevers as photodetectors and filters with much higher Q factors than are currently possible by conventional electronic methods. Recent progress in the fabrication of nanomechanical resonators (cantilevers) has resulted in high-frequency cantilevers (up to 100 MHz) with quality factors ($Q = 10^5$), which are at least three orders of magnitude higher than for electronic filters. These ultralow mass devices enable an entirely new paradigm in photonics: sensitive detection of photon momentum rather than conventional detection by photon energy. In this approach the AM signal reflected by the Earth's surface (in the case of airborne sensor) or aerosols and molecular backscattering in the atmosphere actuates a cantilever by resonant light pressure or by optical gradient forces (see Fig. 1). In a variant of the local sensor (see Fig. 2), the light emerges from a multipass absorption cell and actuates the cantilever. Optical actuation of cantilevers by light has been demonstrated [1, 2]. In our case, the cantilever functions both as a high-frequency detector and as a high-Q filter. By choosing the cantilever resonance frequency appropriately, the proposed sensor can be made to operate in the thermal noise limit [3]. The use of cantilevers in FM-LIDAR and local FM-sensors in this way offers the possibility of detecting low absorptions and concentrations with unprecedented sensitivity.

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